APPENDIX C

EXAMPLE DESIGN PROBLEM

C-1. Purpose and Scope

The design example in this appendix illustrates predesign considerations and design principles that relate to the development of plans for a hazardous waste landfill and surface impoundment. Both facilities are assumed to be developed for an existing government owned, contractor-operated, industrial installation that manufactures small arms, ammunition and chemical materials. Where appropriate, the design engineer is directed to primary references for additional details, as well as to several figures in this TM for typical layouts and design details. As needed, assumptions underlying the selection of design elements will be noted.

C-2. Design Example

a. Site Scenario. The general location, size, hydrogeologic conditions, climate, and anticipated wastes for this hypothetical installation are summarized below:

- A 2,000-acre installation in the Midwest characterized by rolling hills above an adjacent valley region.
- Located within Seismic Zone 2, as defined by paragraph 3-4 of TM 5-809-10.
- Annual precipitation of 39 inches and mean total snowfall of 17 inches.
- Average daily maximum temperature of 80°F for May through October and average daily minimum of less than 32°F for December, January and February.
- Annual pan evaporation is 45 inches, with 76 percent of the evaporation occurring from May through October.
- 100-year, 24-hour design storm of 5.8 inches.
- Design freezing index of 500 for the region.
- Silty clay topsoil 1 to 3 feet in thickness.
- Glacial till clayey soils interspersed with discontinuous sand stringers to a depth of 200 feet over a shale bedrock.
- Ground water (which occurs within on-site swales) found at depths ranging from 90 to 120 feet below the surface; flow direction is toward the adjacent valley.
- Ground water of drinking water quality exists in only limited amounts; it is not a measurable source of recharge to the valley aquifer.
- Liquid wastes (designated for the surface impoundment) consist of acidic wastewater; maximum volume of liquid waste storage is 2,000,000 gallons.
- Solid hazardous wastes (for landfilling) consist of (1) incinerator ash containing lead (10 cubic yards (cy) per day), and (2) sludges produced by an acid neutralization process (20 cy per day).

b. Pre-design evaluation. Given the scenario described above, the design engineer will initially review available documents and evaluate site conditions and waste types and quantities. In addition, the engineer will perform additional hydrogeologic services identified in paragraph 3-3 of this TM including geologic mapping of the proposed site locations, drilling borings and excavating test pits, and testing soils for geotechnical properties. Based on the available information, logs of borings, and additional test results, engineering properties of soils and related pre-design calculations and evaluations will be made; these are summarized below:

(1) Available data verify that both the surface impoundment and the landfill can be developed with adequate' vertical separation, and hydraulic separation from ground water. Construction areas are well above the 100-year flood plain. Both units allow excavations which can provide needed topsoils, clayey soils for soil berms and secondary liners, and soil cover needs for the operation and closure of the landfill.

(2) Tests of clayey soils determine that they exhibit a Liquid Limit of 40 and a PI of 18, a dry density of 105 pcf, an optimum moisture content of 19 percent, and a permeability of 3 x 10-8 cm/sec at optimum plus 4 percent. When they were subjected to the hazardous wastes to be contained, the clayey soils exhibited a permeability of 5 x 10-8 cm/sec.

(3) Based on stability analysis, earthfill berms or dikes constructed with on-site clayey soils will have an adequate factor of safety for stability under static and seismic loadings, provided they are constructed with a 12-foot-minimum crest width, a maximum height of 25 feet, and side slopes of 3:1 or less (see para 3-3).

(4) Based on current publications on compatibility testing (EPA SW-870), supportive information from several lining manufacturers, and accelerated testing (using the waste to be contained), the following liners were determined to be suitable for the project: chlorinated polyethylene (CPE), chlorosulfonated polyethylene (CSPE), and high density polyethylene (HDPE) (see para 6-3).

(5) In accordance with the Universal Soil Loss Equation, (EPA SW-867, page 37) A = RKLSCP, where

(eq C-1)

R, the rainfall erosion index for the location, is 175

K, the erodibility factor for the above topsoil, is 0.21
C, the cover factor for well established grass-like plants is, 0.01
P, the erosion control practice for normal conditions, is 1.0
A, the soil loss in tonslacre/year, limited to < 2 per RCRA guidance documents

(a) The LS landslope factor must be < 5.4; therefore the following design slopes could be used:

Slope	*Slope Length*	*Vertical Height*
3:1	34	11
4:1	85	21
5:1	180	35

(b) Based upon a design freezing index of 500 for the region, the silty clay topsoil when barren can freeze to a depth of about 2 feet (EPA SW-867, page 29).

(6) The sludges produced by the acid neutralization process can be solidified by adding nonbiodegradable absorbents or by solar drying; when absorbents are used, the resultant waste volume is doubled. The net May through October evaporation rate of 24 inches allows solar drying (the net annual evaporation of 5 inches precludes use of solar evaporation ponds).

c. Required design elements and procedures.

(1) Design elements for the surface impoundment include:

- a dike along two perimeters of the impoundment
- run-on control ditches
- a double liner system with leak detection which includes a protective cover, a primary synthetic liner, a leak detection system, and a secondary soil liner.
- inlet and outlet pipes (12-inch-diameter pipes to be provided; these will be equipped with automatic flow controls to prevent overtop ping).
- ground-water monitoring wells

(2) Design elements for the landfill include:

- an earthfill berm along the end of the landfill
- run-on/run-off control facilities
- a double liner system with leak detection, which includes a leachate collection system, a primary synthetic liner, a leak detection system and a secondary soil liner
- final cover (for closure)
- ground-water monitoring wells

(3) Figure 5-1 illustrates layouts for typical surface impoundments and a landfill, and figures 5-2, 6-1, 6-2, 6-5, 6-6, 6-7 and 6-10 show design details.

(4) Proposed dimensions for the 2, 000, 000 gallon capacity surface impoundment are a 10-foot liquid depth with a 2-foot freeboard, 3:1 construction slopes, base dimensions 100 feet wide by 180 feet long (inboard crest-to-crest dimensions are 172 feet by 252 feet).

(5) Proposed dimensions of the 200, 000 cy landfill' are approximately 20 feet deep, with inboard crest-to-crest dimensions 400 feet wide by about 800 feet long. The size of the landfill is based upon the following disposal volumes:

Containerized ash	10 cy/day
Sludges (20 cy/day, with 1/2 dried without volume change, and 112 solidified by absorbents, with a doubled volume)	30 cy/day
Operational soil cover needs (2:1 waste:soil ratios for 40 cy of waste)	20 cy/day
TOTAL	60 cy/day
	1,200 cy/mo
	14,400 cy/yr [2]

(6) When 100-year flood levels are determined to be above the project area, earthfill levees of compacted impervious soil can be constructed to prevent flooding (see figure 6-1).

(7) Liner systems details for this hypothetical facility (including leak detection and leachate collection systems) are illustrated in figures 6-2 and 6-5. The proposed incorporation of a secondary soil liner for the two waste units in this example problem (and for any waste unit) should be based upon the premise that there is little or no potential for ground-water flow into the detection system. The construction of project earthfills and proposed clay liners (in accordance with placement requirements described in paragraph 6-3 and in EPA SW-870) will provide an adequate secondary liner and soil subbase for other liner elements at this facility.

(a) Given a DA requirement to limit the number of field seams and locate such seams to minimize the potential for leakage, field panel widths of approximately 100 feet for the primary synthetic liner are proposed. The liner material for the two waste units will be restricted to CPE and CSPE, based upon compatibility testing and panel size needs. The actual panel sizes and layouts are contingent upon required spacing for the leak detection and leachate collection systems and will be developed after selecting these design dimensions.

(b) Calculations for the leak detection and leachate collection systems, and material selections, are:

- Infiltration rates for system design:
  —Assuming seepage through the secondary

[1] A desired service life of 15 years requires about 200,000 cubic yards of capacity.

[2] Based upon 5 days/week, 20 days/month, 240 days/year.

liner due to a 10-foot head of liquid acting on the clay liner:

$Q = KiA$ (Darcy's Law) where (eq C-2)

$$q = \frac{Q}{A}$$

i = (liquid head plus liner thickness/liner thickness)

$$q = Ki$$

$$q = Ki = (1 \times 10^{-7}\text{ cm/sec}) \left(\frac{2835\text{ ft/day}}{\text{cm/sec}}\right)\left(\frac{13\text{ feet}}{3\text{ feet}}\right)$$

$$= 1.23 \times 10^{-3}\text{ ft/day (0.4 inches/month)}$$

—Assuming infiltration through a clay loam soil cover of q = 2.6 inches/month (EPA SW-870, page 267).

- Pipe spacing for leak detection system (L), the collection drain spacing, for a 1-foot-thick sand layer, $K \geqslant 1 \times 10^{-3}$ cm/sec, can be calculated:

$$Q = KiA$$
$$Q = q(L)(1) = 1.23 \times 10^{-3}L$$
$$K = 1 \times 10^{-3}\text{ cm/sec}$$

$$i = \frac{(1 + 0.01L)}{L/2}$$

$$A = 1\text{ foot} \times 1\text{ foot}$$

$$(L) = \left(\frac{1}{1.23} \times 10^{-3}\right)\left(1 \times 10^{-3}\right)(2835)\frac{(1 + .01L)(1 \times 1)}{L/2}$$

$$L^2 - 46.1L - 4610 = 0$$
$$L = 95\text{ feet}$$

Therefore sand with a permeability slightly greater than 1×10^{-3} cm/sec would be required in connection with a 100-foot panel/pipe spacing interval.

- Pipe spacing for leachate collection system for a 1-foot-thick sand layer, $K \geqslant 1 \times 10^{-3}$ cm/sec, assuming infiltration through the final cover at 2.6 inches/month

$$L = \left(\frac{1}{7.22 \times 10^{-3}}\right)2.835\left(\frac{(1+.01L)}{.5L}\right)(1 \times 1)$$

$$L = 32\text{ feet}$$

For a 1-foot-thick sand layer $K \geqslant 1 \times 10^{-2}$ cm/sec, 2.6 inches/month infiltration

$$L = 136\text{ feet}$$

Therefore sand with $K \geqslant 1 \times 10^{-2}$ cm/sec could be used in connection with 100-foot panel/pipe spacing interval.

- Piping ratio between clay liner and sand, using design criteria for plastic clay (Cedergren, page 181):

$$\frac{D_{15}\text{ of sand}}{D_{85}\text{ of clay}} < 5^{3}\text{ (piping ratio)}$$

$$\frac{D_{60}\text{ of sand}}{D_{10}\text{ of sand}} < 20\text{ for single layer filter}$$

with sand gradation guideline specs:

D_{10} of sand = #50 = 0.295 mm
D_{15} of sand = #50 = 0.295 mm
D_{60} of sand = #16 = 1.168 mm
D_{85} of clay = #200 = .074 mm

$$\frac{D_{15}}{D_{85}} = \frac{.295}{.074} = 4$$

$$\frac{D_{60}}{D_{10}} = \frac{1.168}{.295} = 4$$

Thus the proposed sand drainage layer can be used without any geotextile filter cloth or fabric.

- Pipe slot size
  Using design criteria of:

$$\frac{85\%\text{ size of filter materials}}{\text{slot width}} > 1.2$$

For rounded clean drain rock:
D_{85} = 3/8 inches

$$\text{Maximum slot width} = \frac{3/8}{1.2} = .31\text{ inch}$$

For sand:
D_{85} = #4 sieve = .185 inches
Maximum slot width = .185/1.2 = .154 inch

[3] "If a protected soil is a plastic clay, the piping ratio often can be much higher than 5 or 10, as indicated by U.S. Army Corps of Engineers practice previously noted," Cedergren, Harry R., 1977. *Seepage, Drainage, and Flow Nets*, p 183.

Standard slot size selected for the piping is 0.102 for both sand and drain rock drainage layers.

- Pipe capacity, leak detection system:

For the proposed pond with a width of 100 feet, and pipe spacing of 100 feet, and $q = 1.23 \times 10^{-3}$ ft/day

$$Q\,\text{req'd} = qA = 1.23 \times 10^{-3}(100\text{ feet})(100\text{ feet}) \qquad \text{(eq C-3)}$$

$$= \frac{12.3\text{ ft}^3}{\cancel{\text{day}}} \times \frac{\cancel{\text{day}}}{24\,\cancel{\text{hr}}} \times 3600\,\frac{\cancel{\text{hr}}}{\text{sec}}$$

$$= 1.42 \times 10^{-4}\text{ cfs}$$

For 2-inch pipe:

$$Q = \frac{1.49}{n} A R^{2/3} S^{1/2} \text{ (Manning's equation),}$$

where (eq C-4)

$n = .01$
$s = .005$

$$R = \frac{D}{4} = .5\text{ inch (flowing full)}$$

$$= .042\text{ foot}$$

$$\therefore Q = \frac{1.49}{.01}(.022)(.042)^{2/3}(.005)^{1/2}$$

$$= .028\text{ cfs}$$

$Q > Q$ req'd,

therefore 2-inch pipe is adequate

- Pipe capacity for leachate collection system
For a landfill with a base width up to 400 feet, and a pipe spacing of 100 feet and $Q = 7.22 \times 10^{-3}$ ft/day, "Q required" can be calculated following the approach described for the leak detection system. Although such calculations show that a 2-inch pipe could also be used for leachate collection, a 4-inch pipe will be installed to ensure adequate capacity for removing any leachate that might accumulate within the landfill during operations.
- Pipe structural stability:
Positive projecting installation for maximum vertical pressure (EPA SW-870, page 378)

For maximum vertical pressure:

δ_v = max. vertical pressure (eq C-5)
$\delta_v = W_f H_f + wz$, where

W_f, density of refuse fill, is 50 pcf
H_f, height of fill above pipe, is 40 feet max.
w, density of backfill (drain rock), is 110 pcf
z, height of backfill (above pipe), is 1 foot
$\Delta y/B_c$, allowable pipe (deflection), is .05 to .1
E^1, passive soil modules, is 90% ± relative compaction

$$\therefore \delta_v = 50(40) + (110)(1) = 2110\text{ psf} = 14.7\text{ psi}$$

Adjustment for pipe slots:

for slot size = .102 inch
slot space = .25 inch → 32 rows of slots per foot

$$L_p = \frac{\text{Length of slots (inches)}}{\text{foot of pipe (ft)}} = 3.264\text{ in/ft}$$

Pipe stress (EPA SW-870, page 382) is:

(eq C-6)

$$(\delta_v)\text{ design} = \frac{12}{12 - L_p} \times (\delta_v)\text{ actual}$$

$$= \frac{12}{12 - 3.264}(14.7\text{ psi})$$

$$= 20.2\text{ psi}$$

$$\frac{\delta_v}{\Delta y/B_c}$$

for $\Delta y/B_c = 0.05$

$$\frac{\delta_v}{\Delta y/B_c} = \frac{20.2}{.05} = 404$$

for $\Delta y/B_c = 0.1$

$$\frac{\delta_v}{\Delta y/B_c} = \frac{20.2}{.1} = 202$$

From the monograph in figure V-6, EPA SW-870:

For E^1 = 700 psi

and $\frac{\Delta y}{B_c} = .05$	2″ Sch 40 (extrapolated solution) or 4″ Sch 80
for $\frac{\Delta y}{B_c} = .1$	2″ Sch 40 4″ Sch 40

Selected pipes (with allowable deflections of 5 percent) are 2-inch Schedule 40 PVC pipe, (or equivalent alternative), for the leak detection system, and 4-inch Schedule 80 PVC pipe (or equivalent alternative) for the leachate collection system.

(c) Based upon these calculations, the design engineer will develop liner panel installation plans with leak detection and leachate collection networks for the surface impoundment. Design elements will include:

- A base grade configuration which slopes at 0.5 percent across the 100-foot width of the pond, with a crest-to-trough distance of 50 feet along the pond's 180-foot length to accommodate the leak detection pipe network.
- Two-inch slotted detection pipes in trenches over the troughs, with risers up the side slopes within the drainage layer.
- A 36-mil reinforced primary synthetic liner.
- A 1-foot sand/riprap protective cover.

(d) Based upon the calculations outlined above, liner, leak detection and leachate collection design elements for the landfill include:

- A base grade configuration which slopes at 0.5 percent across the 400-foot width of landfill, with crest-to-trough distances of 50 feet along the landfill's length to accommodate the leak detection pipe network.
- A trough along the lower side of the landfill to accommodate a collection drainpipe to connect leachate laterals to a sump area.
- Two-inch slotted detection pipe, as described above for the surface impoundment.
- A 36-mil reinforced primary synthetic liner.
- Four-inch slotted leachate collection pipes surrounded with rounded drain rock, within the 1-foot thick drainage layer.

(8) Gas control measures for the facility will be limited to a few pipe vents for the surface impoundment. The absence of organic materials below or within the landfill and surface impoundments minimizes the likelihood of air pressure developing below proposed liners. Nevertheless, since even a small amount of gas pressure can lift synthetic liners in impoundments, atmospheric pipe vents should be considered at selected perimeter locations of the surface impoundment.

(9) Surface water control features for the proposed surface impoundment and landfill will be similar to those illustrated in figure 5-1. They will include ditches and drainage pipes normally used to prevent flow into active portions of waste units. Upon closure, the run-on control ditches of the landfill carry run off from closed final cover areas as well.

(a) Run-on control ditches, V ditches and the typical trapezoidal ditch shown in figure 6-7, can be constructed with adequate slopes to carry run-off volumes. For example, with contributory areas of less than 5 acres, a peak discharge of less than 20 cfs results from the 100-year design storm. (SCS run-off method, with a type C soil classification, a CN value of 70 for grasslands and a steep slope, S > 8 percent.)

(b) A sedimentation basin will be established for the landfill construction area; in addition, sediment control facilities will be utilized at all temporary construction sites.

(c) For the active waste area of the landfill, temporary containment berms can be used to retain run off for treatment when limited run off volumes are involved. By limiting the active waste lift and containment area for the proposed landfill to an area about 200 feet long and 100 feet wide, the run off from the 100-year storm is 72, 000 gallons. This is based on 100 percent run off from a 5.8-inch intensity rainstorm over the active area.

(d) Due to limited evaporation, the run off from active areas should be discharged to the surface impoundment for subsequent treatment. If no additional rainfall run-off control measures are selected (i.e., tarps, restricted operations during rainfall periods), the annual rainfall of 39 inches would produce about 500,000 gallons of liquid.

(10) Ground-water monitoring wells will be installed in accordance with federal regulations, one hydraulically upgradient of the facility (to provide background water quality data) and three downgradient to detect contaminant discharge. Well design and sampling procedures will reflect details presented in paragraph 8-3.

(11) Special design elements needed for this facility are impoundment dikes and overtopping controls (part of the plant equipment), with a 2-foot freeboard. Addressed under liner details are requirements for developing adequate anchor pads for the "over-the-line" inlet/outlet pipes and appurtenant structures for flow control. The only penetrations allowed will be liner "boots" clamped to penetrations for the leak detection and leachate collection pipe risers, and gas vents within the berm crest of the levee of the surface impoundment (see EPA SW-870, figure IV-22, page 371). No wind dispersal provisions will be needed since the ash is containerized.

(12) As segments of the fill are brought to final grade, final cover for the proposed landfill will be placed to minimize infiltration of precipitation. As stated in EPA SW-870, table V-5, page 267, water balance calculations result in a 2.6-inch maximum monthly infiltration for a 2-foot clay cover. Final cover slopes (selected based on LS factors) will be a minimum 3 percent and 5:1 or less; assuming proper placement procedures, settlement is not expected to pose a design constraint. The final cover system will consist of a 20-mil PVC liner placed over a 2-foot soil liner (permeability of 1 x 10-7 cm/sec), a drainage layer of sand, and topsoil to facilitate vegetative growth. General details for the final cover are illustrated in figures 6-7 and 6-10.